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# Estimating Characteristics of Chemical Explosions in New England and Eastern Kazakhstan Using Local and Regional Seismic Data



A.L. KAFKA
M. JACOBSON-CARROLL
S. D'ANNOLFO

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Solid Earth Geophysics Branch

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One of the problems associated with monitoring a comprehensive nuclear test ban treaty is that of discrimination between small explosions and earthquakes based on seismic data. Chemical explosions are used routinely in the mining and construction industries in both the United States and the Soviet Union. These chemical explosions usually occur at very shallow depths (a few tens of feet), and probably are all shallower than a few hundred meters. Most nuclear explosions are detonated at depths of less than about one kilometer, and the deepest underground nuclear explosions are a few kilometers deep. On the other hand, most earthquakes occur deeper in the earth's crust. Thus, accurate estimation of the depths of seismic sources can be helpful in discriminating earthquakes from explosions. During the past several years, the Principal Investigator (PI) for this summer project has been studying the use of short-period Rayleigh waves (Rg) as a depth discriminant for seismic sources in New England. The research that we conducted this summer was primarily an extension of the PI's research on Rg as a depth discriminant. In addition, we investigated other aspects of estimating characteristics of chemical explosions from local and regional seismic data. The primary goal of our research this summer was to record seismic data at field sites located at near-regional distances from quarry blasts.

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## Contents

# Illustrations

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# Estimating Characteristics of Chemical Explosions in New England and Eastern Kazakhstan Using Local and Regional Seismic Data

## 1. INTRODUCTION

One of the basic problems associated with monitoring a comprehensive nuclear test ban treaty is that of discriminating between small explosions and earthquakes based on local and regional seismic data. Chemical explosions are used routinely in the mining and construction industries in both the United States and the Soviet Union. Although the specific depths of these industrial explosions are often unknown, they usually occur at very shallow depths (a few tens of feet), and probably are all shallower than a few hundered meters. Most nuclear explosions are detonated at depths of less than about one kilometer, and the deepest underground nuclear explosions are on the order of a few kilometers deep. On the other hand, most earthquakes occur deeper in the earth's crust, and earthquakes in the upper kilometer are probably not very common. Thus, accurate estimation of the depths of seismic sources can be helpful in discriminating earthquakes from explosions.

During the past several years, the Principal Investigator (PI) for this summer research project has been studying the use of short-period Rayleigh waves (Rg) as a depth discriminant for seismic sources recorded in New England[1, 2, 3] (Kafka, 1988, 1989a, 1989b). Using seismic data recorded by the

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1. Kafka, A.L. (1988) Investigation of Rg waves recorded from earthquakes and explosions in New England, 10th Annual DARPA/AFGL Sym., San Antonio, TX, May, 24-30.
2. Kafka, A.L. (1989a) Rg as a depth discriminant for earthquakes and explosions: A case study in New England, 11th Annual DARPA/AFGL Sym., Fallbrook, CA, May, 32-39.
3. Kafka, A.L. (1989b) Rg as a depth discriminant for earthquakes and explosions: A case study in New England, submitted to *Bull. Seism. Soc. Am.* (accepted pending revisions).

New England Seismic Network (NESN; a regional seismic network operated by Boston College) we have been able to use New England as a "laboratory" for Rg wave propagation in various geological regions (Figures 1, 2 and 3). In addition, data recently recorded in eastern Kazakhstan, USSR by the National Resources Defense Council (NRDC) in the vicinity of the Soviet Test Site makes it possible to compare Rg waves in New England with Rg waves in eastern Kazakhstan.

For the small chemical explosions that are routinely recorded in New England (mbLg 1.0 to 1.5), methods that use Rg as a depth discriminant appear to be applicable to seismograms recorded at epicentral distances ranging from about 20 km to at least 170 km. The presence of Rg on a seismogram indicates that the source occurred in the upper few kilometers of the crust. Thus, the problem of developing a method for using Rg as a depth discriminant is essentially the problem of deciding how to determine if Rg is present on a seismogram. The specific methods that have been developed by the PI for determining the presence of Rg on a seismogram are described in References 2 and 3.

The research that we conducted this summer at the Geophysics Laboratory (GL) was primarily an extension of the PI's research on Rg waves as a depth discriminant. In addition, we investigated other aspects of estimating characteristics of chemical explosions from seismograms recorded at local and regional distances.

## 2. OBJECTIVES OF THE RESEARCH EFFORT

During the past several years, field data have been recorded from chemical explosions in New England by personnel from Boston College's Weston Observatory in cooperation with personnel from GL as well as a number of other institutions. We have focused our attention on the San-Vel quarry in Littleton, MA (Figures 4, 5 and 6) because that quarry is conveniently located near Weston Observatory and the GL and because the operators of that quarry have been very cooperative. The primary goal of our research this summer was to record additional seismic data from quarry blasts in the San-Vel quarry.

Rg waveforms are affected by variations in the geology and shallow crustal structure along the propagation path as well as by variations in source characteristics. To separate the effects of the source and path on Rg waveforms, we have been investigating Rg wave propagation in New England, with particular attention on southern New England. As part of this summer research project, we investigated the variation of Rg waveforms for quarry blasts located at the San-Vel quarry and recorded at NESN station WES (Figure 4). The purpose of this aspect of our research is to get a better idea of the variation of Rg waveforms generated by quarry blasts. To augment the NESN data, we installed field stations near the sources as well as at near-regional distances (about 15 to 40 km from the source).

Another objective of this research was to begin a systematic investigation of all available information regarding the characteristics of quarry blasts and other chemical explosions in New England. We obtained information from blasting logs maintained by quarry operators to begin cataloging information such as source depth, configuration of blasting holes, total number of pounds of explosives detonated, and maximum number of pounds of explosives per delay. Based on this information, we will be able to investigate the effects of these source characteristics on local and regional seismograms.

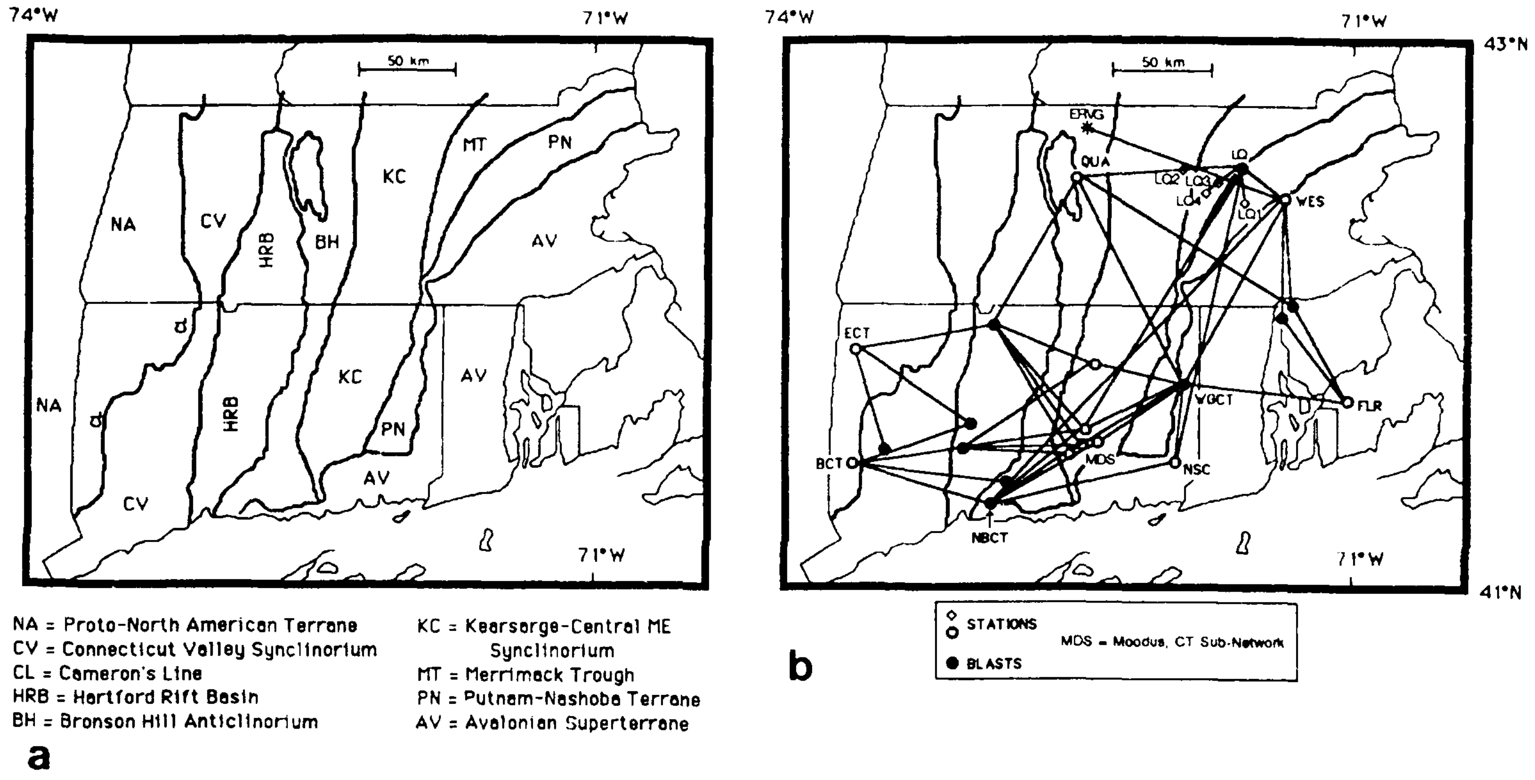


Figure 1. Map of southern New England showing (a) boundaries of lithotectonic terranes and other major geological features of the southern New England Appalachians, and (b) propagation paths of Rg waves discussed in this paper. In (b), solid circles are quarry and construction blasts, open circles are seismic stations of the New England Seismic Network (operated by Weston Observatory), and open diamonds are field stations installed (previous to this study) to record quarry blasts located at the San-Vel quarry in Littleton, MA (LQ). Rg paths are from numerous studies summarized by Kafka (1988).[4] ERVG indicates the epicenter of the Erving, MA earthquake of June 14, 1984.

4. Kafka, A.L. (1988) Earthquakes, geology and crustal features in southern New England. *Seism. Res. Let.*, **59**(4):173-181.

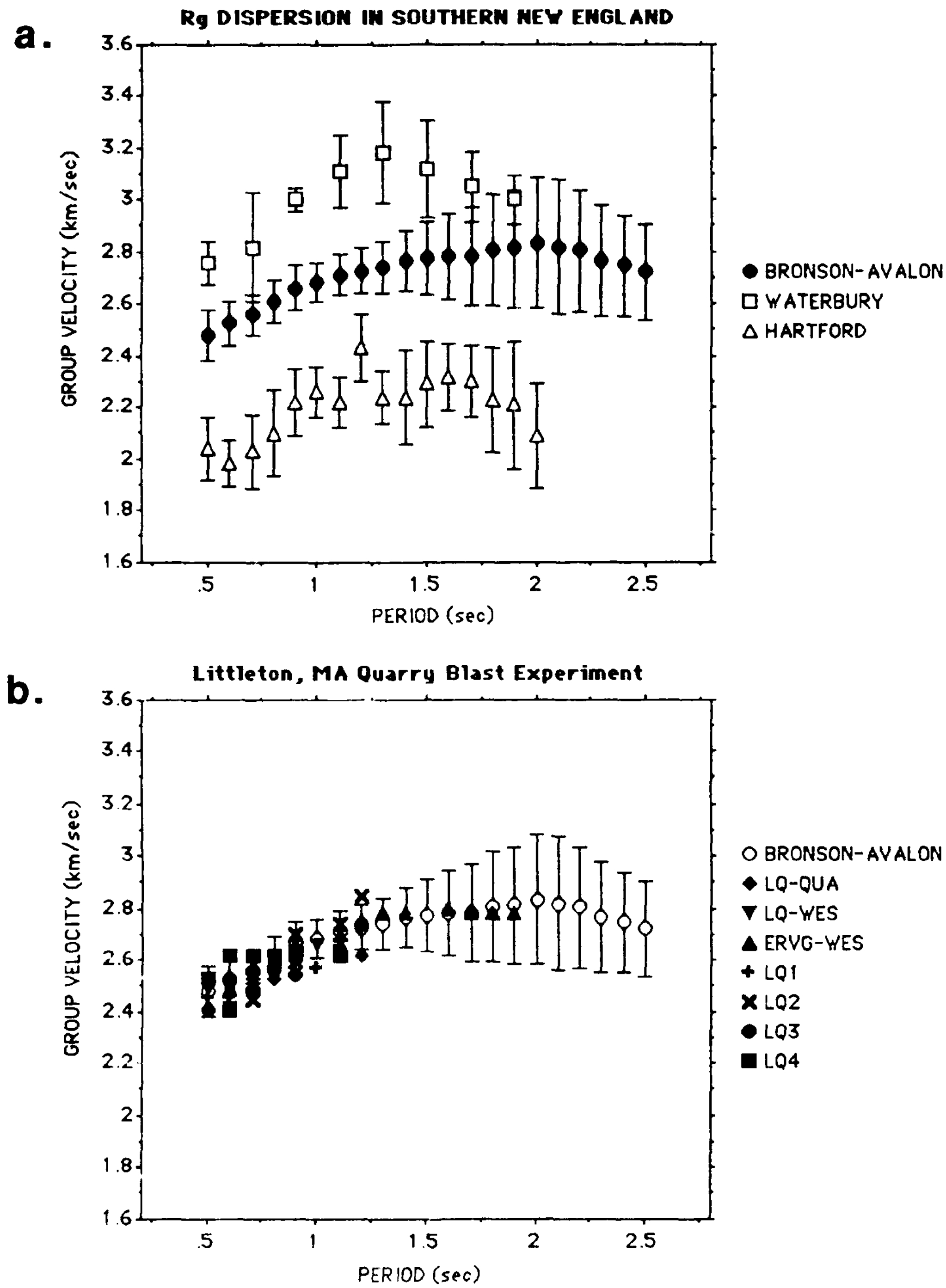


Figure 2. (a) Rg dispersion data for southern New England from various studies summarized by Kafka (1988).[4] Mean and standard deviation is shown for the Bronson-Avalon (BADR), Waterbury , the Hartford dispersion regions. These statistics represent a subset of the paths shown in Figure 1, but all of the data from the paths in Figure 1 are consistent with the classification shown here. (b) Comparison of Rg dispersion from field data recorded in 1987 from the San-Vel quarry with dispersion in the BADR, and with dispersion data for the path from the Erving, MA earthquake to WES.

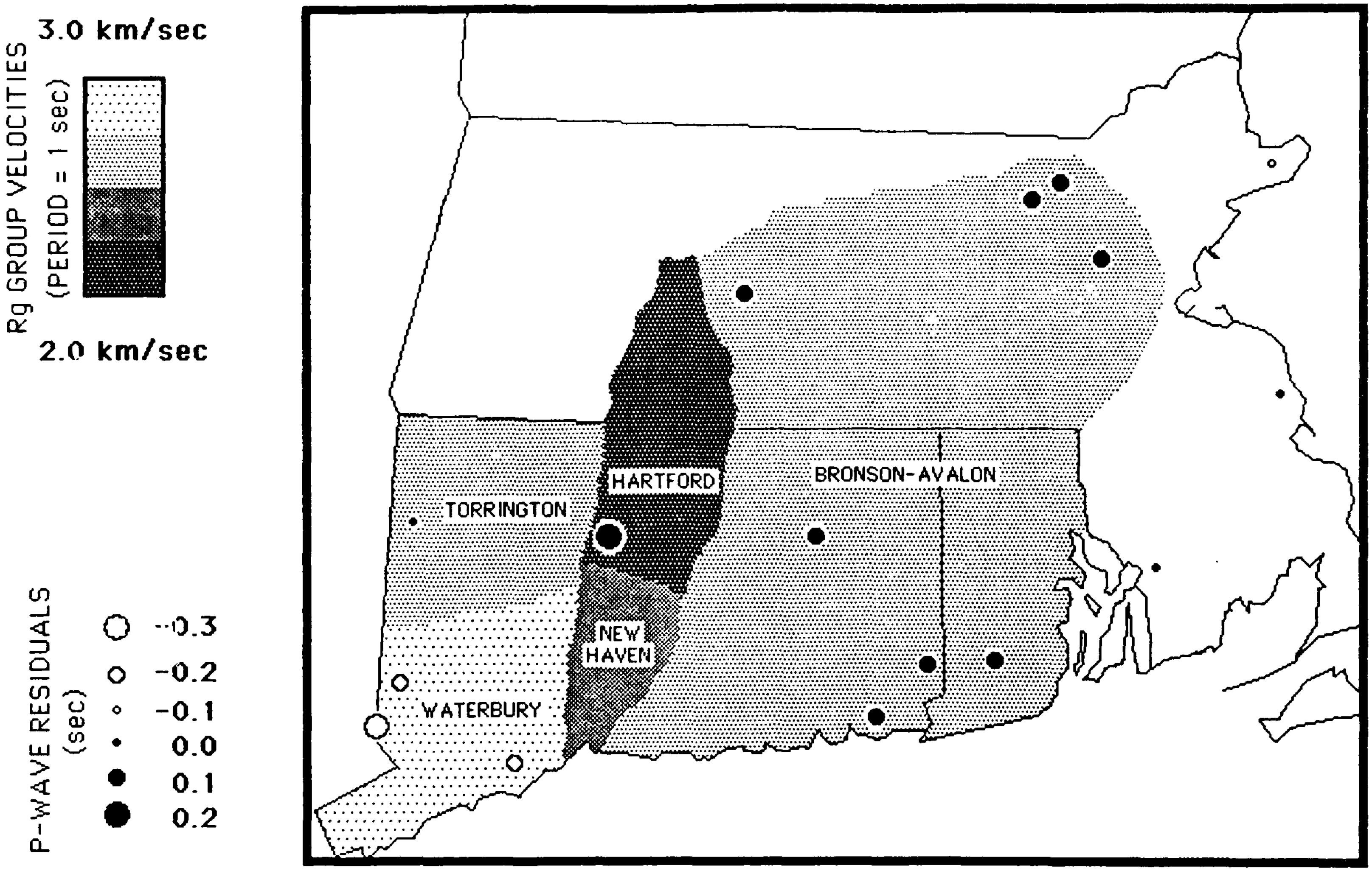


Figure 3. Map of Rg dispersion regions and teleseismic P-wave residuals in southern New England. Teleseismic residuals (indicated by dots and circles) are from Taylor and Toksoz (1979)[5] and Peseckis and Sykes (1979).[6]

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5. Taylor, S.R. and Toksoz, M.N. (1979) Three-Dimensional Crust and Upper Mantle Structure of the Northeastern United States, *J. Geophys. Res.* **84**:7627-7644.
6. Peseckis, L. and Sykes, L.R. (1979) P-wave residuals in the northeastern United States and their relationship to major structural features (abstract), *EOS, Trans. Am. Geophys. Un.* **60**:311.

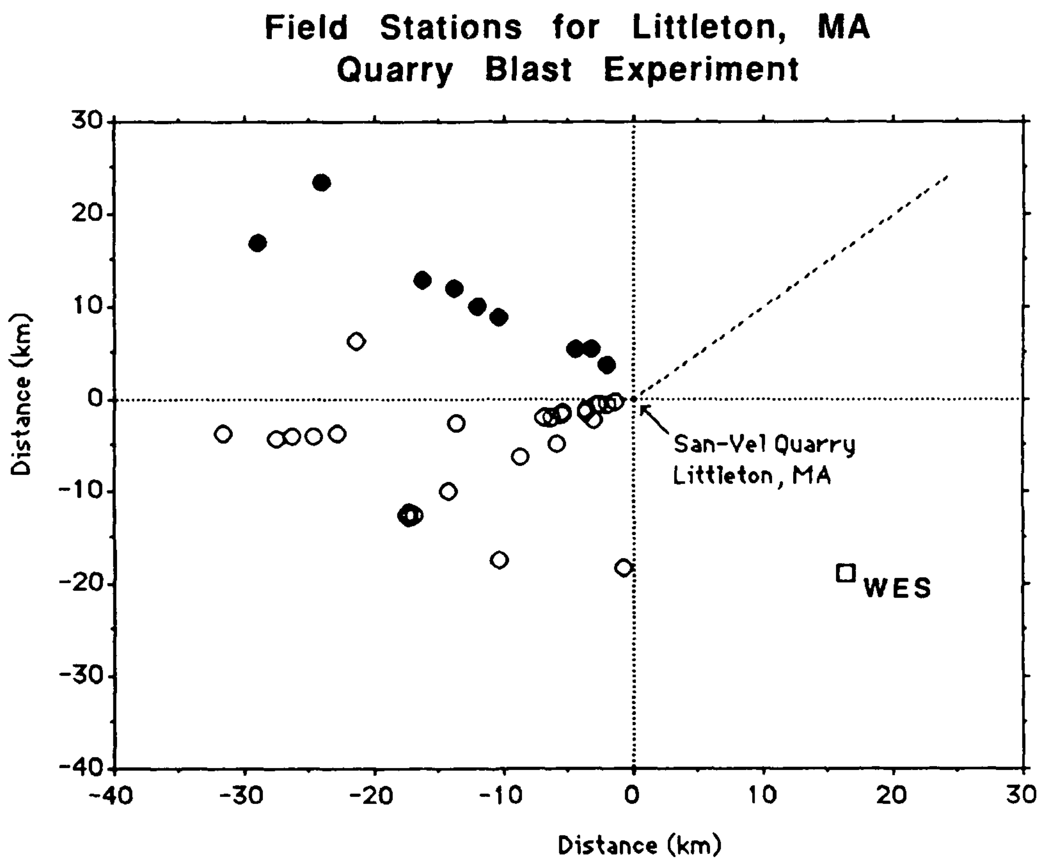


Figure 4. Field stations installed to record quarry blasts detonated at the San-Vel quarry in Littleton, MA. Open circles indicate stations installed in 1987 and 1988. Closed circles indicate stations installed as part of this study. During the last phase of this study, stations were installed along the direction indicated by the dashed line.

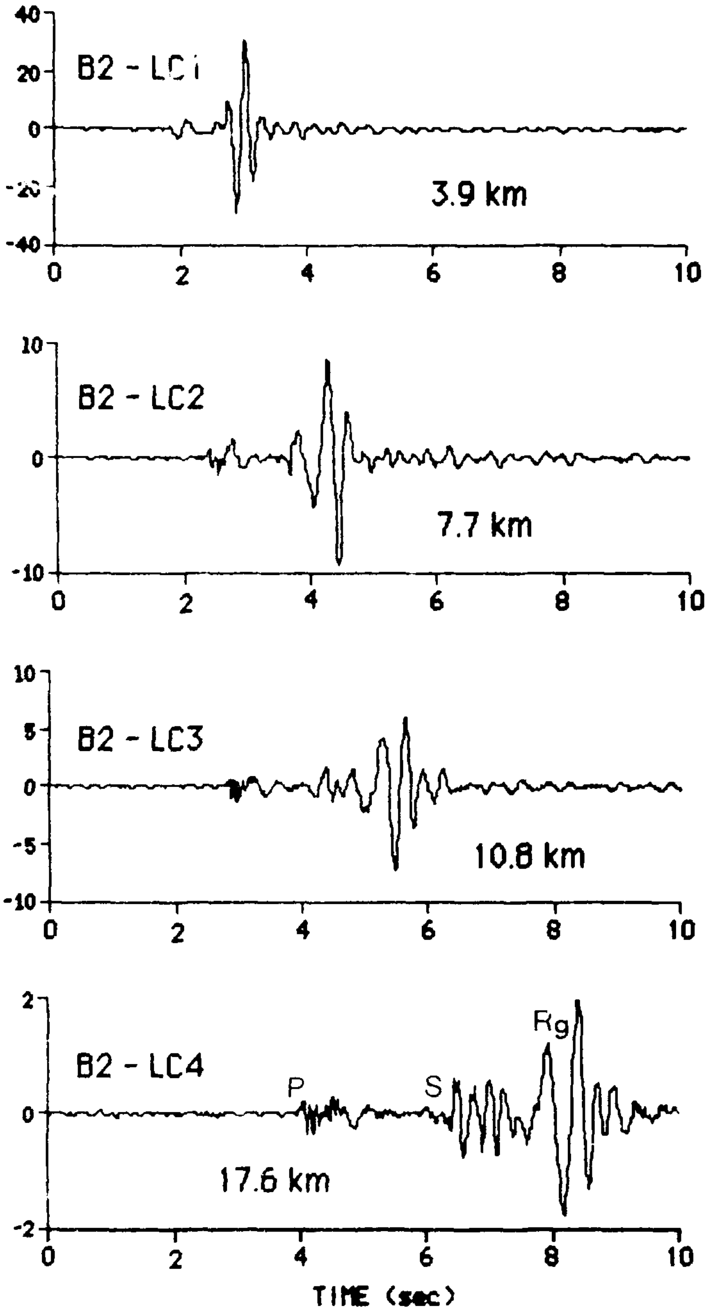


Figure 5. Seismograms of a San-Vel quarry blast recorded as part of a July 21, 1987 field experiment. These seismograms were recorded along a line extending southwest of the quarry. Distances from the shot are given (in km) for each trace.

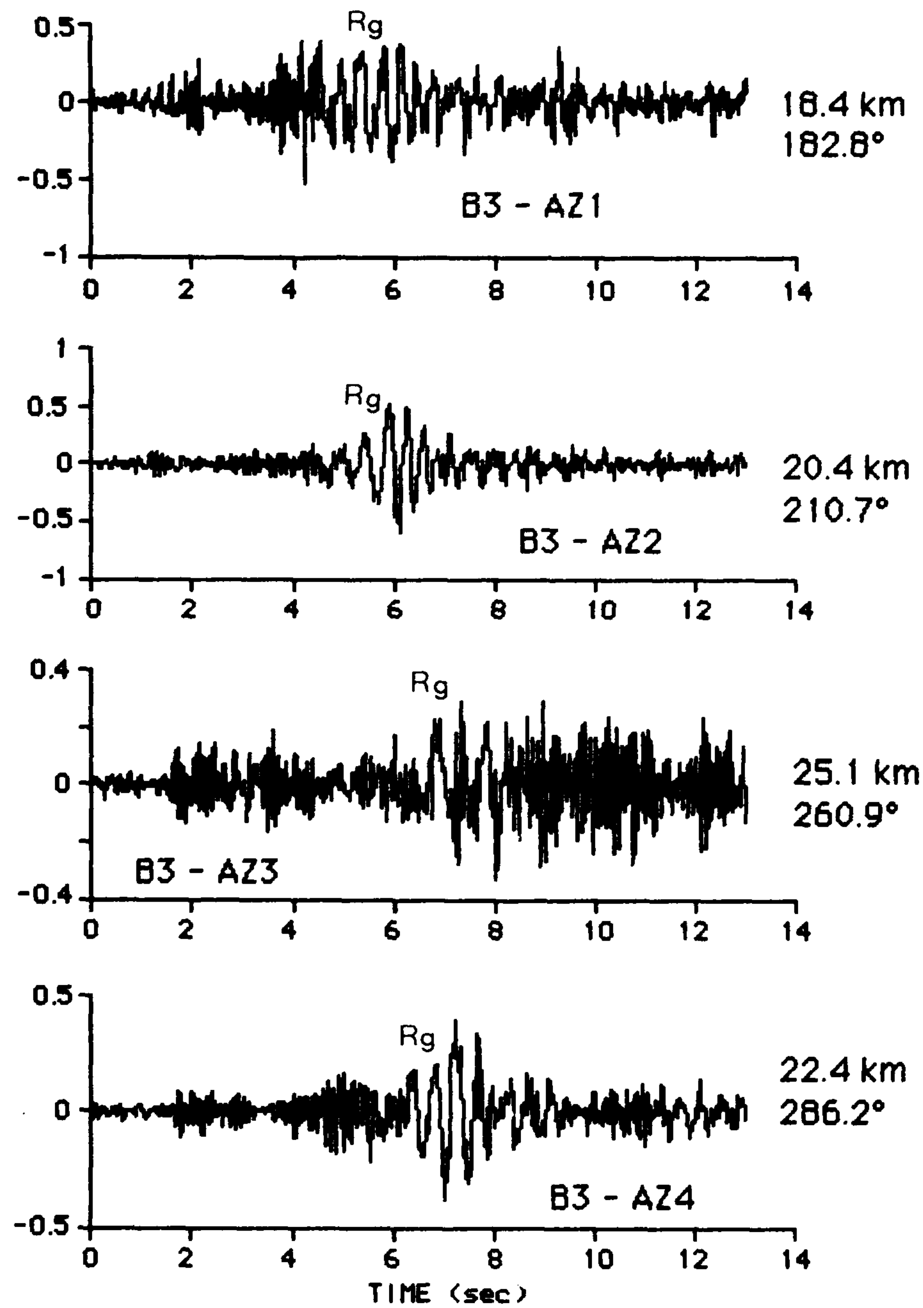


Figure 6. Seismograms of a San-Vel quarry blast recorded as part of a July 29, 1987 field experiment. These seismograms were recorded at four different azimuths around the quarry (at distances of 18 to 25 km) to investigate the radiation pattern of the blast. Azimuths (measured from north) are given (in deg) for each trace.

An important aspect of this research is to compare seismograms of explosions in New England with those recorded in the vicinity of the Soviet Test site in eastern Kazakhstan. We have obtained a data tape from the Center for Seismic Studies that contains digital seismograms recorded at stations operated by the National Resources Defense Council (NRDC) in the vicinity of the Soviet test site. Those seismograms have been transferred to the Boston College VAX computer, and we are beginning to process the NRDC data using the methods that we are developing for estimating depth from observed Rg waves. The NRDC seismograms will be studied to compare the excitation and propagation of Rg waves in eastern Kazakhstan with that in New England. The work conducted this summer on this aspect of our research is a pilot study for a Research Initiation Program grant proposal.

## 3. QUARRY BLAST RAYLEIGH WAVE SIGNALS

### 3.1 Rg as a Depth Discriminant

The strongest Rg signals recorded by the NESN are generally in the period range of about 0.5 to 1.5 sec. In that period range Rg displacement is essentially confined to depths shallower than 5 km, with most of the Rayleigh wave energy in the upper 2 or 3 km. Sources deeper than about 4 km would not be expected to generate strong Rg signals. Thus, if Rg can be clearly identified on a seismogram, the source is most likely very shallow (less than 3 km). Observed Rg waves can, therefore, be used as a depth discriminant, provided that the Rg phase can be identified and distinguished from other phases. Kafka[2] suggested a method for identifying the Rg phase that involves comparing amplitudes in the arrival-time window where the Rg wave energy is expected to arrive with amplitudes in the arrival-time window where S and Lg waves are expected to arrive. The amplitudes in the various arrival time windows are measured for specific periods using a narrow bandpass filter (NBF) analysis.[7] This method of identifying Rg is currently being tested for events recorded in New England. An important aspect of this research is to apply the same method to seismograms recorded by the NRDC in the vicinity of the eastern Kazakhstan test site, and to compare the effectiveness of the method in the two different regions.

### 3.2 1989 SFRP/GSRP Experiments in Southern New England

In the beginning of the summer we met with the San-Vel quarry operators to set up procedures for obtaining information about the characteristics of the blasts (such as the amount of explosives detonated, the location of the blasts in the quarry, and the times of the blasts). We also spent time in the field, familiarizing ourselves with the geological characteristics of the area and obtaining permission from land owners for setting up specific recording sites on their property. Based on these preparatory steps, we recorded blasts detonated on 26 June and 7 July at the San-Vel quarry to test our recording and analysis procedures.

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7. Dziewonski, A.M., Bloch, S., and Landisman, M. (1969) A technique for the analysis of transient seismic signals, *Bull. Seis. Soc. Am.* **59**:427-444.

Our first complete field experiment of this summer's project was conducted on 11 July using GL's Terra-Technology DCS-302 portable seismic recorders. We installed a line of portable seismic stations extending northwest of the San-Vel quarry (Figures 4 and 7). During July, we also met with the operators of the San-Vel quarry to obtain detailed information about shot times, locations of the shots within the quarry, and the amount of explosives used in a given shot. Using this information, we are analyzing data recorded in the past from the San-Vel quarry at NESN stations along with data recorded in the field this summer to investigate the relationship between characteristics of the quarry blast sources and characteristics of seismograms recorded at a distance.

By the end of the summer we completed two additional field experiments along the line extending northwest of the San-Vel quarry. We successfully recorded and archived sixteen vertical-component seismograms from nine sites. Horizontal components were also recorded at all sites, but we have so far only archived the vertical components because we are primarily interested in the vertical component of the Rg wave. Additional data were recorded, but some of the field data still remain to be transferred from field data cassettes to the mainframe computer.

Most of the field data recorded from San-Vel quarry blasts are from stations installed at sites to the west of the quarry (Figure 4). NESN station WES routinely records data to the southeast of the quarry. Thus, we decided that it was important to complete the azimuthal coverage by installing stations to the northeast of the quarry. Our last experiment of the summer involved recording along a line extending northeast of the San-Vel quarry (dashed line in Figure 4). We are currently transferring data recorded at two sites along that line from field data cassettes to the Boston College VAX computer. We hope to continue our work this fall and next spring to obtain more complete recording along that northeast line.

We are also analyzing data recorded at NESN stations from numerous additional blasts detonated at the San-Vel quarry as well as blasts detonated at two other quarries in eastern Massachusetts (the Keating quarries, one located in Lunenburg, MA and the other in Dracut, MA).

## 3.3 Seismograms Recorded in Eastern Kazakhstan

We have begun to analyze seismograms of quarry blasts in the vicinity of the Soviet Test Site (obtained from the NRDC data tapes). Figure 8 shows the seismogram of a blast located at the Karagayly quarry recorded at NRDC station KKL (a distance of 27 km). Using a location and origin time for that blast obtained from Thurber et al.,[8] we analyzed the dispersion of the Rg waves using the same methods that we are now routinely using in New England. The results suggest that Rg velocities along that path are quite similar to those of the Bronson-Avalon dispersion region in southern New England (Figures 2 and 3).

To compare the seismogram shown in Figure 8 with seismograms of quarry blasts recorded in New England, we deconvolved the NRDC seismogram to ground motion and then convolved it through the NESN instrument response curve. This gives an estimate of what the Karagayly blast might have looked like if it were recorded by one of the NESN stations. It is interesting that the Karagayly blast,

8. Thurber, C., Given, H., and Berger, J. (1989) Regional seismic event location with a sparse network: Application to eastern Kazakhstan, USSR, (preprint), submitted to *J. Geophys. Res.*

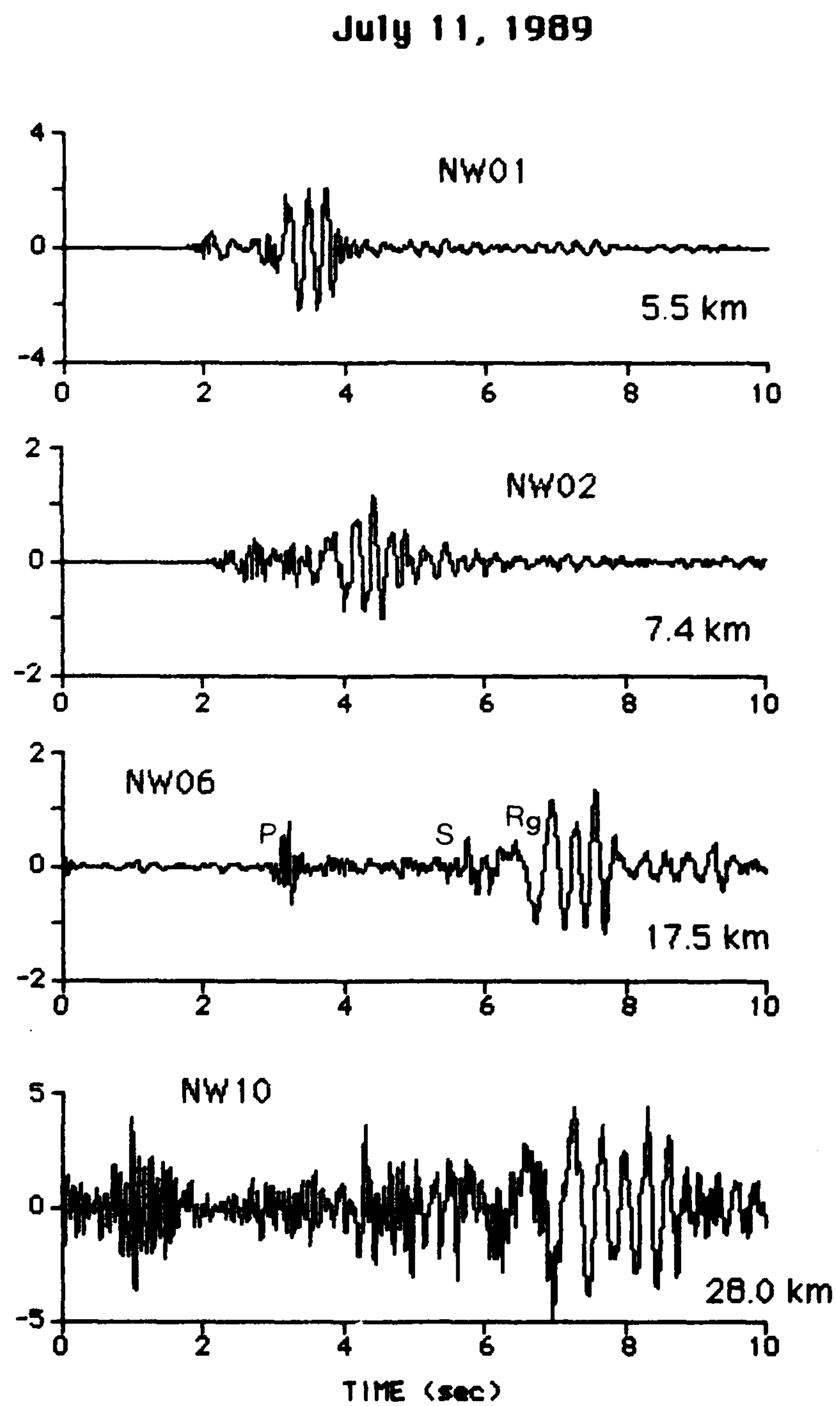


Figure 7. Seismograms of a San-Vel quarry blast recorded as part of a July 11, 1989 field experiment conducted this summer. These seismograms were recorded along a line extending northwest of the quarry. Distances from the shot are given (in km) for each trace.

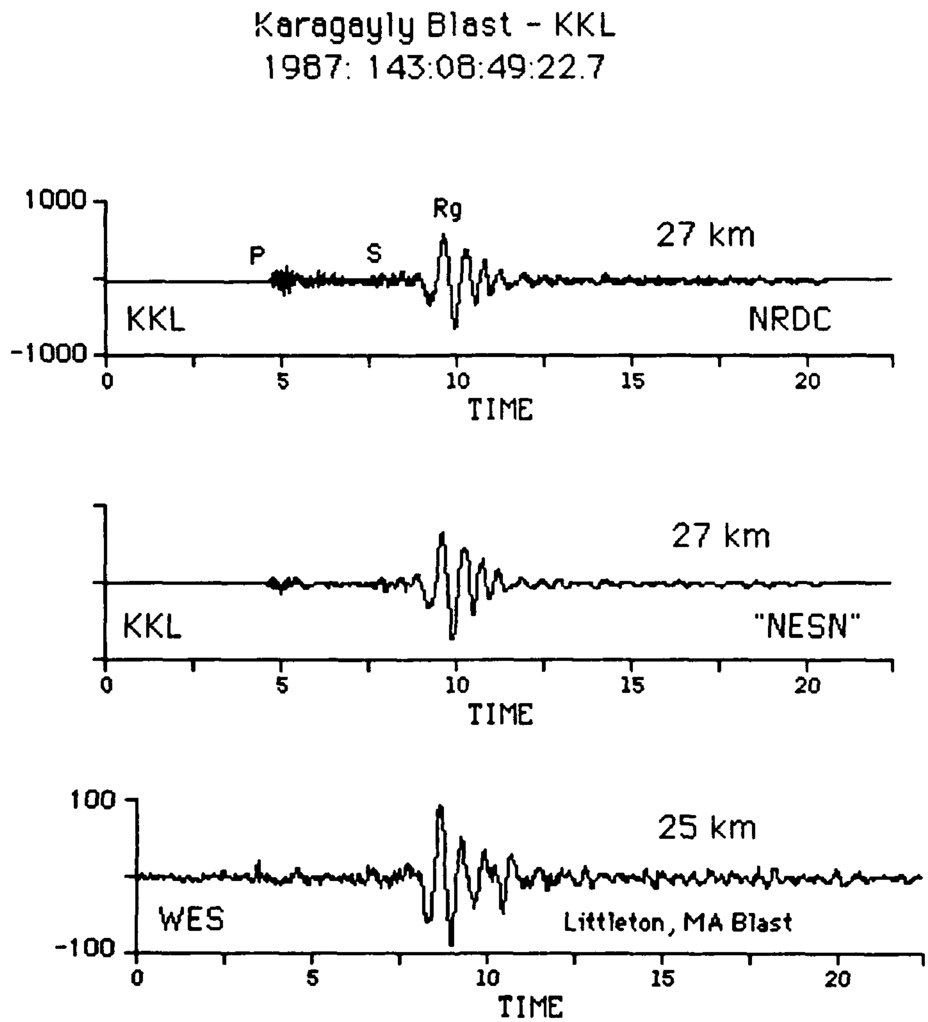


Figure 8. Comparison of seismograms from a quarry blast in eastern Kazakhstan and a quarry blast in New England. The New England quarry blast (lower seismogram) was located at the San-Vel quarry in Littleton, MA and recorded at station WES, a distance of 25 km. The eastern Kazakhstan blast (upper seismogram) was located at Karagayly and recorded at NRDC staion KKL (Karkaralinsk), a distance of 27 km. The middle seismogram is the Karagayly blast after being deconvolved to ground motion and then convolved with the NESN instrument response.

when processed in this manner, looks quite similar to the San-Vel quarry blast. We will process additional seismograms from the NRDC data tape to investigate the variation of Rg velocities and waveforms in eastern Kazakhstan.

## 4. RECOMMENDATIONS

Although there are some practical problems associated with using Rg as a depth discriminant, regional seismograms are generally complex, and it is unlikely that any regional discriminant will work in all cases. It seems clear that, in any region where event depth must be determined from a limited number of seismic observations, some measure of the presence (or absence) of Rg wave energy on seismograms should be considered as a possible depth discriminant.

The Rg methods being developed as part of this study should be tested on seismograms of as many blasts and earthquakes as possible. These tests should be conducted on seismic data recorded in New England and in eastern Kazakhstan, as well as in other areas.

It is important to continue recording seismograms of quarry blasts in New England to develop an extensive data base that could be used to investigate the characteristics of seismograms recorded from small explosions.

## References


1. Kafka, A.L. (1988) Investigation of Rg waves recorded from earthquakes and explosions in New England, 10th Annual DARPA/AFGL Sym., San Antonio, TX, May, 24-30.
2. Kafka, A.L. (1989a) Rg as a depth discriminant for earthquakes and explosions: A case study in New England, 11th Annual DARPA/AFGL Sym., Fallbrook, CA, May, 32-39.
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4. Kafka, A.L. (1988) Earthquakes, geology and crustal features in southern New England, *Seism. Res. Let.*, **59**(4):173-181.
7. Dziewonski, A.M., Bloch, S., and Landisman, M. (1969) A technique for the analysis of transient seismic signals, *Bull. Seis. Soc. Am.* **59**:427-444.
8. Thurber, C., Given, H., and Berger, J. (1989) Regional seismic event location with a sparse network: Application to eastern Kazakhstan, USSR, (preprint), submitted to *J. Geophys. Res.*